COLLEGE OF AGRICULTURE UNIVERSITY OF NEBRASKA
AGRICULTURAL EXPERIMENT STATION
RESEARCH BULLETIN 29

Further Studies on the Effect of Environment on Potato Degeneration Diseases

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DEPARTMENT OF PLANT PATHOLOGY

LINCOLN, NEBRASKA
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CONTENTS

SUMMARY

1. The experimental results clearly show that of the environmental factors studied, light, soil moisture, and soil temperature have very little or no effect upon the foliage symptoms of any of the degeneration diseases studied in this investigation.

2. High soil moistures and high soil temperatures appear to increase the severity of the tuber symptoms of the spindle-tuber disease. However, high soil temperatures also have a tendency to change the shape and color of the tubers of plants not affected with spindle-tuber.

3. The effects of air temperature on the foliage symptoms of the degeneration diseases have again been found to be very pronounced and it appears to be the most important factor studied in the inhibition or masking of the foliage symptoms.

4. In addition to the masking of mottling, wrinkling, ruffling, rugosity, curling, rolling, and brittleness in mosaic plants, it was found that spotting, streaking, burning, and leaf-dropping on Bliss Triumph plants affected with rugose mosaic were eliminated at a temperature of 25° C.

5. The symptoms of the various mosaic diseases on the Green Mountain variety were more pronounced than on Bliss Triumph and the masking effect at high temperatures was not as great. However, the symptoms of each disease studied were in general the same as those occurring on the Bliss Triumph variety.

6. Masking of symptoms was greatest at high temperatures with mild mosaic, while spindle-tuber symptoms were masked at low temperatures.

7. When mosaic and spindle-tuber occurred on the same plant, the severity of the mosaic symptoms decreased, while those of spindle-tuber increased, at high temperatures.

8. As a rule the masking of symptoms was not as marked at high temperatures with combinations of degeneration diseases as with a single mosaic.

9. The several and distinct diseases described by Schultz and Folsom were found to come true to type by tuber perpetuation when the possibility of infection with other diseases the previous year had been eliminated. The addition of new disease symptoms occurred

when the plants were grown in the field subject to infection by insect transmission.

10. The splitting up of combinations of diseases in different tubers from the same plant and also in different eyes of the same tuber was noted.

11. Yellow dwarf appeared as a disease distinct from the others studied. The temperature effect was the reverse of that occurring with mosaic. At 25° the disease was very severe, while at 15° C. no symptoms appeared.

12. The application of these results to field and experimental work with these diseases is discussed.

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INTRODUCTION

The identification of potato degeneration diseases in the field is extremely difficult owing to the number of diseases now described, their manifestation on different varieties, the combination of several diseases on the same plant, and the further splitting up of these combinations into separate diseases. The influence of environmental factors in intensifying or inhibiting the symptoms of these diseases also increases the difficulty of diagnosis.

Additional data on the effect of environment on the symptoms of these various diseases would be of considerable value. The practical application of such data in the work of seed selection and in the extensive seed certification work now being carried on in the United States is obvious. Such data would also be of great value in the proper interpretation of the results of inoculation and field transmission studies of these diseases. One of the authors, Goss (3), has recently shown the effect of certain environmental factors, chiefly temperature, on the masking of mosaic symptoms. The application of these results to the seed certification work has been found of value but the necessity for the investigation of the effect of other factors on the symptoms of these diseases is evident.

In the present investigation the effect of environmental factors has been studied with the purpose of determining the limiting factor or factors in the masking of the symptoms, in the hopes of simplifying a complex problem by the elimination of certain other factors which have often been cited as causing a masking.

The tendency of many investigators has been to group the mosaic diseases of various host plants under one general heading on the basis of cross-inoculations. This attitude is directly contrary to that of many other potato disease investigators, who have differentiated potato mosaic into a number of separate and distinct diseases. While no inoculation

studies have been made in the present investigation, the variety of the disease material used with the available history of the seed has allowed for a study regarding the permanence of these disease types which was thought well worth including. Accordingly, data are presented regarding the splitting up of combinations of these diseases and their varietal manifestation which is not strictly a study of environment, but which may serve to emphasize previously published work of other investigators and may be of some aid in the solution of other problems regarding these diseases.

EXPERIMENTAL METHODS

In the following work, enough soil (3 parts sod soil to 2 parts sand) was mixed at one time for all experiments. The soil moisture equivalent[1] was determined to be 15 per cent (dry weight). About 10 kilograms of soil were placed in 3-gallon earthenware jars or galvanized containers and the moisture content was then adjusted to the desired point and kept approximately constant by methods previously described (5).

Two greenhouses kept approximately at temperatures of 15° and 25° C. were used for several experiments. Repeated fumigations were made and no insects known to be invectors were observed during the experiments. In other experiments, more accurate control of temperature was obtained by the use of "temperature cases," "soil temperature tanks," and artificial refrigeration. A detailed description of all control apparatus mentioned in this bulletin has previously been published by the authors (5).

In order to minimize the experimental error, the plants to be studied under different environmental conditions were all grown from seed pieces from the same mother tuber. When this was impossible owing to the small size of the tuber or the number of conditions under which the plants were to be grown, tubers from the same hill of the previous year were used.

Detailed notes on all the seed tubers were made as to size, shape, weight, and spindle-tuber symptoms. Records of the date of emergence were made, and the first observations on the plants were recorded when they were 10-15 cm. high; further records were made every two weeks thereafter. Each of the 17 symptoms listed in the tables was recorded if present, as slight, medium, or severe. Comparisons were made

[1] The authors are indebted to Mr. J. C. Russel of the Department of Agronomy for the determination of soil moisture equivalents, which are expressed in this publication by the abbreviation "M. E."

with healthy control plants growing under the same conditions. The number, weight, and appearance of all tubers produced were recorded at the end of the experiment.

The data presented on the following pages were compiled by using the average symptoms of typical plants of each disease. Owing to lack of space it is impossible to record the average symptoms of all plants grown or all the observations made on each plant. The examples here used are considered to be representative of all the plants in the experiments.

In addition to the detailed records previously mentioned, photographic records were obtained of all seed tubers, and in many cases of the plant or of typical leaves, and also of representative tubers produced. The tuber photographs allowed for careful comparison of the seed tuber with its progeny. The numerous plant and leaf photographs taken at different stages of growth were found to be of great aid in the final interpretation of the data, and served as a check on the tabulated observations of the symptoms.

SOURCE OF SEED

With a few exceptions all of the seed tubers used in these experiments were obtained thru the courtesy of Dr. Donald Folsom of the Maine Agricultural Experiment Station. Some of the seed tubers were obtained in the fall of 1923 and had been grown in Maine that year. The remainder were grown in Nebraska in 1923 from seed obtained from Maine in 1922.

Bliss Triumph units listed as Me. 1 to 40 were obtained from Maine in the fall of 1923. This lot of seed was listed by Dr. Folsom as containing the following diseases: leaf roll, mild mosaic, leaf rolling mosaic, spindle-tuber, and mild mosaic + spindle-tuber. One-half of each of the tubers was grown by Dr. Folsom in Maine and the other half used in the following experiments. In every case the diagnosis of the disease present in the half tuber grown in Maine was the same as for the half grown in the greenhouse in Nebraska. This served as a further check on the purity of the disease types used in these experiments.

Bliss Triumph units listed as Neb. 4, A to G were from seed obtained from Maine in 1922 and grown in the field in western Nebraska in 1923. No precautions were taken to prevent infection by insect transmission in the field and so, in some instances, new combinations of diseases developed in the plants grown from the progeny. Where the diseases did not appear true to type the plants were not used in the data

presented in this paper except in a few cases where notations of the differences occurring are presented. The various units of the original seed obtained from Maine were listed as containing the following diseases: mild mosaic, medium plus mosaic which appeared to be a combination of spindle-tuber + rugose mosaic, spindle-tuber, spindle-tuber + mild mosaic, and curly dwarf which appeared to be a combination of spindle-tuber + leaf-rolling mosaic.

Green Mountain tubers listed on page 22 were obtained from Maine in the fall of 1923. These tubers were produced in the field and were subject to infection with other diseases thru uncontrolled insect transmission. These tubers were listed as containing leaf roll, leaf rolling mosaic, mild mosaic, rugose mosaic, and spindle-tuber. The plants grown from these tubers showed that considerable infection, chiefly with rugose mosaic, had occurred the previous year, as noted on page 23.

Samples of tubers affected with yellow dwarf were obtained thru the courtesy of Mr. L. M. Fenner of Cornell University. One lot of tubers of the White Rose variety and another lot of the Early Rose variety, both of which had been grown in the field in New York in 1923, were used in these tests.

Control plants for all experiments with the Bliss Triumph variety were grown from healthy seed obtained from plants selected in certified fields the previous summer and no mosaic appeared in any of the controls. Healthy Green Mountain tubers were obtained from Dr. Folsom.

RELATION OF LIGHT TO DISEASE SYMPTOMS

An attempt was made to determine the possible effect of different intensities of artificial light on the disease symptoms. Seed affected with the following diseases was used in the experiment: spindle-tuber + mild mosaic, medium plus mosaic, curly dwarf, mild mosaic, leaf-rolling mosaic, and rugose mosaic. Healthy seed was used as controls. Plants grown under different light intensities were either from the same seed tuber or the tubers were from the same hill. The soil moisture content was kept at 1¼ M. E. and all plants were grown at a temperature of 15°–18° C. Detailed notes were made when the plants were 10–15 cm. high and every two weeks thereafter.

The light chambers previously described (5) were employed. Mazda lights of 50, 100, 200, 300, 500, 750, and 1000

watts were used. These lights were on continuously thruout the experiment. Another set of plants were grown in the same greenhouse in sunlight.

Observations of the disease symptoms were difficult, owing to the type of growth occurring under the conditions of the experiment. The plants in all the light chambers showed considerable lengthening of the internodes and the leaves were much reduced in size. At the lowest light intensities there also occurred a great deal of chlorosis and some leaf-dropping on both healthy and diseased plants.

Results:—No effect of the different degrees of light intensities on the symptoms of the various diseases was evident at any time during the experiment. The symptoms of each disease appeared the same as those recorded for other plants grown at the same temperature in sunlight, (p. 15), and need not be presented here.

It was therefore evident that a decrease in the intensity of light from that normally occurring in the greenhouse, even with increased duration (continuous light), had no effect on the symptoms of the diseases studied. It was unfortunate that lights of much greater intensity than those used in this experiment were not available as it is very possible that an increase in the light intensity would have had a very considerable effect on the foliage symptoms, particularly on mottling.

Schultz and Folsom (6) note that a "reduction in sunlight decreased apparent dwarfing, and increased mottling," in experiments with various types of potato mosaic. The masking of mosaic symptoms, particularly mottling, has been noted by several writers in the high-altitude, dry-land sections of the west. This phenomenon is of common occurrence in western Nebraska. The intense sunlight prevailing at this high altitude, probably about 10,000 foot candles on clear days, may possibly affect the degree of mottling. In the experiments reported above, the greatest light intensity used, as obtained from a 1000-watt light, produced approximately 450 foot candles. Even tho the light was used continuously, the total amount of light received by the plants would be much less than that occurring in western Nebraska on a clear day. Field observations, however, are subject to considerable error because of the presence of other uncontrolled factors. Increase in sunlight is usually associated with increase in temperature, which may be the limiting factor involved. Further studies should be made under controlled conditions using greater light intensities than those here employed.

RELATION OF SOIL MOISTURE TO DISEASE SYMPTOMS

The following experiment was planned to determine what effect, if any, the moisture content of the soil has upon the symptoms of the various degeneration diseases.

Methods:—All plants were grown in 3-gallon earthenware jars containing about 10 kilograms of soil. The moisture content and the moisture equivalent of the soil were determined before planting and the moisture content was then adjusted to the desired points and kept approximately constant by methods previously described (5). A total of 136 jars were used. These were divided into 2 sets, and placed in greenhouses maintained at approximate temperatures of 15° and 25° C. Each set was divided into 4 lots, having different soil moisture contents. The soil moisture contents were held at 2/3, 1, 1¼, and 1½ of the moisture equivalent.

Bliss Triumph seed tubers from practically all the disease lots listed on page 7 were used. Some of the seed tubers were divided into 4 pieces and grown at the 4 different moisture contents at the same temperature. Others were divided and grown at different temperatures but with the same moisture content. Thus all comparative tests with each disease were made as far as possible with seed from the same mother tuber, or at least from the same hill of the preceding year.

Observations were made on each plant every 2 weeks after the plants were 10 to 15 cm. high until the death of the plant. Detailed notes were made of the presence and severity of all symptoms and additional notes taken as necessary; these were supplemented by photographic records in many instances.

Results:—No correlation could be made at any time during the experiment between the symptoms of the various diseases and the moisture content of the soil. There was a tendency for slightly increased ruffling, rolling, uprightness, and rigidity at the higher moisture contents but the same tendency was manifest in the control plants, and the changes in these symptoms were very slight. The curly dwarf plants grown at 25° C. appeared to have slightly more severe symptoms at a moisture content of 1¼ M.E. than at the lower and higher moisture contents; but as the plants at this moisture content were from a different hill than the others, no conclusions could be drawn. With the medium plus mosaic plants there was a slight increase in the severity of spotting, streaking, burning, and leaf-dropping with increasing moisture contents, but the increase was very slight. The plants affected with spindle-tuber sometimes showed a tendency to produce

TABLE 1—*Relation of soil moisture to disease symptoms*

Mild Mosaic

Source of seed	Plant No.	Soil moisture content[2]	Symptoms[1]															
			Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping	Early death
		M. E.																
Neb. 4B5—4	66	2/3	2	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..
Neb. 4B5—4	67	1	2	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..
Neb. 4B5—5	69	1¼	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..
Neb. 4B5—5	71	1½	1	..	3	2	3	..	..	..	..	..	..	..	..	..	..	..

[1]The severity of the symptoms is graded numerically as follows: 1 = slight, 2 = medium, and 3 = severe; 0 or the absence of any symbol means the symptom did not appear.

[2]Based on soil moisture equivalent.

tubers with more severe symptoms at the higher moisture contents but these results were not consistent.

Table 1, compiled from the notes taken on typical mild mosaic plants grown at 15° C., shows no change in the symptoms at the different moisture contents. This is typical of the other plants in the experiment. Plate 1 shows the absence of any effect of the soil moisture content on the control plants and on spindle-tuber plants.

Discussion:—While several workers have observed that during dry seasons the symptoms of mosaic were masked, the results of this experiment do not show any evidence to support these observations, at least as regards soil moisture. It is possible that atmospheric moisture might be a factor in changing the symptoms, but the observations of the authors on plants grown in different greenhouses often having different relative humidities have not indicated that this would occur, so that no experimental studies have been attempted.

It has been pointed out in a previous paper (3) that changes in the symptoms of these diseases during wet weather can often be correlated with decreased temperature, which is undoubtedly a greater factor than soil moisture. More extensive studies, however, are being made regarding the possible changes in the tuber symptoms of spindle-tuber plants grown at different soil moisture contents, as this disease has been reported to be particularly severe under irrigation (7).

RELATION OF SOIL TEMPERATURE TO DISEASE SYMPTOMS

While numerous workers have noted the effect of air temperature on the symptoms of potato mosaic, the authors are not aware of any experimental studies of the effect of soil temperature on the symptoms. The following experiment was therefore planned to determine whether or not different soil temperatures would have any effect on the symptoms when the air temperature was kept at an optimum point for the appearance of symptoms.

Methods:—The following diseases were studied in this experiment on the Bliss Triumph variety: mild mosaic, spindle-tuber, spindle-tuber + mosaic, curly dwarf, and medium plus mosaic. Healthy Bliss Triumphs were used as controls. Seed pieces from the same tuber or from tubers from the same hill were cut into equal sized pieces and planted at 4 different soil temperatures. The plants were grown in galvanized containers holding 10 kilograms of soil, which was held at a soil moisture content of 1¼ M.E. Immediately after

planting, the containers were placed in soil temperature tanks held at the following temperatures: 14°, 18°, 22°, and 26° C. The air temperature was kept at approximately 15° C. thruout the experiment.

Records were made as in previous experiments.

Results:—An examination of the data presented in Table 2 will show that no change in the symptoms occurred on the foliage of plants affected with mild mosaic (Plate 2, A), spindle-tuber, or spindle-tuber + mosaic. The symptoms of mild mosaic at all temperatures were typical for the disease. The plants affected with spindle-tuber showed only a slight dwarfing and uprightness. No ruffling was observed. These symptoms of spindle-tuber are typical for all plants grown at an air temperature of 15° C. The spindle-tuber + mosaic plants were grown from seed obtained from spindle-tuber plants which had evidently acquired mosaic in the open field the previous summer.

While the soil temperature had no effect on the above-ground symptoms of all these plants, there was a very marked change in the type of tuber produced.

With high soil temperatures the elongation and paler color of the tubers produced by the plants affected with spindle-tuber were more severe (Plate 2, B). However, tubers from healthy plants and from mild mosaic plants often tend to show these same tuber characteristics at high soil temperatures (Plate 2, C). This same phenomenon regarding the change in shape and color of tubers grown at high soil temperatures has been noted by L. R. Jones, *et al.* (4) in their investigation on potato scab. This fact made it very difficult to distinguish between tubers affected with spindle-tuber grown at low temperatures and healthy or mosaic tubers grown at high temperatures. Further investigations of this temperature effect on the tuber symptoms are being undertaken.

The curly dwarf and medium plus mosaic tubers produced weak, spindling plants at all temperatures. With these two diseases, germination was greatly delayed. The plants were weaker and more spindling with very small leaves at the higher temperatures, and the leaf symptoms of mosaic were not as marked under these conditions, as shown by the medium plus mosaic plants listed in Table 2.

From this experiment we may conclude that soil temperature has no effect on the above-ground symptoms of mild mosaic and spindle-tuber. High soil temperatures tend to increase the length of the tuber and decrease the color, not only in spindle-tuber progeny but also in the progeny of

TABLE 2—*Relation of soil temperature to disease symptoms*

Source of seed	Plant No.	Soil temperature °C.	Symptoms[1]																Tuber symptoms[2]
			Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping	Early death	
MILD MOSAIC																			
29A	25	14	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
29B	26	18	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
29C	27	22	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
29C	28	26	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	2
SPINDLE-TUBER																			
40A	29	14	1	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	1
40B	30	18	1	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1
40C	31	22	1	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1
40D	32	26	1	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	2
SPINDLE-TUBER + MOSAIC[3]																			
Neb. 4E32—1	5	14	3	..	3	3	3	..	1	..	3	2	2	..	..	1	1	..	1
Neb. 4E32—1	6	18	2	..	3	3	3	..	1	..	3	2	2	..	..	..	1	..	3
Neb. 4E32—1	7	22	3	..	3	2	3	..	1	..	3	2	2	..	..	..	1	..	2
Neb. 4E32—1	8	26	2	..	3	2	3	..	1	..	3	2	2	..	..	1	1	..	3
MEDIUM PLUS MOSAIC (SPINDLE-TUBER + RUGOSE MOSAIC)																			
Neb. 4F15—1	13	14	3	..	3	3	3	..	2	..	3	2	..	..	..	1	1	..	2
Neb. 4F15—1	14	18	3	1	2	3	3	2	3	..	1	..	..	..	1	1	3	..	0[4]
Neb. 4F15—1	15	22	3	..	2	2	2	..	2	..	..	..	..	..	..	1	1	..	2
Neb. 4F15—1	16	26	3	..	1	1	1	..	1	..	..	..	..	..	..	..	..	..	3[5]

[1]See Table 1.
[2]Tuber symptoms refer to tubers showing symptoms of the spindle-tuber disease.
[3]Leaf-dropping was accompanied by corrugations on stem. See footnote p. 19.
[4]No tubers produced.
[5]Leaves and plant very small and weak.

healthy and mosaic plants. With plants affected with a combination of diseases, such as those listed, as curly dwarf and medium plus mosaic, high soil temperature results in such a weak spindling plant that the leaf symptoms are often not observable.

RELATION OF AIR TEMPERATURE TO DISEASE SYMPTOMS

EXPERIMENT IN GREENHOUSE

In the soil moisture experiments previously described, an excellent opportunity was afforded to study the effect of temperature on the symptoms of these diseases. This experiment was run in duplicate in two greenhouses held at temperatures of 15° and 25° C. At the time of the second reading, that is, two weeks after the plants were 10–15 cm. high, some of the plants in the 15° house were changed to the 25° greenhouse and *vice versa*. It was thus possible to observe not only the typical symptoms which appeared at 15° and 25°, but also the changes in the symptoms when plants were changed from one temperature to the other. This allowed for a checking up on the work previously published by one of the authors (3) and also for the further study of diseases of which seed was not available when the previous work was undertaken.

The methods used in this experiment have already been discussed on p. 10.

Results:—The data presented in Table 3 are from a few typical examples of the plants used in this experiment. Space will not permit the tabulation of all the data collected during the experiment. The results of this experiment in general corroborated the conclusions presented in the previous publication (3). The large number of plants used, the greater number of diseases, and the better growing conditions allowed for more detailed notes on the changes in symptoms than was possible in the earlier experiments.

Mottling was again found to be the most constant symptom of mosaic at all temperatures, altho a change in the type and degree of mottling was clearly evident. At 15° C. all mosaic plants showed the prominent mottled appearance of the leaves as shown in Plate 3 A, the light colored areas usually being large and more or less angular. When these plants were changed to 25°, the mottling on the old leaves became less distinct; that is, the sharp line between the light and dark green areas on the leaf disappeared, thus making the mottling indistinct, a condition which will be referred to in this paper as diffuse mottling. The new foliage formed at 25° showed

TABLE 3—*Relation of air temperature to disease symptoms*

Source of seed	Plant No.	Air temperature °C.	Foliage	Symptoms[1]																	
				Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping	Early death	Tuber symptoms[5]
MILD MOSAIC																					
Me. 28B	104	15	all	1	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
Me. 28B	103	15	all	..	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	
Me. 28B	103	25	old	..	..	1	1	1	..	..	..	..	..	..	..	..	..	..	..	
Me. 28B	103	25	new	..	..	1[d2]	0	1	..	..	..	..	..	..	..	..	..	..	..	0
Me. 28D	108	25	all	..	..	0	0	1	..	..	..	..	..	..	..	..	..	..	..	0
Me. 28D	107	25	all	..	..	1[d]	0	1	..	..	..	..	..	..	..	..	..	..	..	
Me. 28D	107	15	old	..	..	1	0	1	..	..	..	..	..	..	..	..	..	..	..	
Me. 28D	107	15	new	..	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
Neb. 4B5—4	67	15	all	2	..	3	2	2	..	..	..	..	..	..	..	..	..	..	..	0
Neb. 4B5—4	68[3]	15	all	..	..	3	3	2	..	..	..	..	..	..	..	..	..	..	..	
Neb. 4B5—4	68	25	old	..	..	3	3	2	..	..	..	..	..	..	..	..	..	..	..	
Neb. 4B5—4	68	25	new	..	..	0	0	0	..	..	..	..	..	..	..	..	..	..	..	0
Neb. 4B5—7	75	25	all	1	..	1[d]	1	1	..	..	..	..	..	..	..	..	..	..	..	0
MEDIUM PLUS MOSAIC (SPINDLE-TUBER + RUGOSE MOSAIC)																					
Neb. 4B18—2	51	15	all	2	..	3	3	2	1	2	..	2	..	..	1	..	1	1	..	0
Neb. 4B18—2	52	15	all	..	..	2	3	2	1	2	..	2	..	..	1	..	..	1	..	
Neb. 4B18—2	52	25	old	..	..	2[d]	2	1	0	0	..	2	..	..	1	..	..	1	..	
Neb. 4B18—2	52	25	new	..	..	1[d]	1	1	0	0	..	2	..	..	0	..	..	0	..	0

TABLE 3 (Continued)—*Relation of air temperature to disease symptoms*

Source of seed	Plant No.	Air temperature °C.	Foliage	Symptoms[1]																	
				Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping	Early death	Tuber symptoms[5]
MEDIUM PLUS MOSAIC (SPINDLE-TUBER + RUGOSE MOSAIC)—Continued																				
Neb. 4B17—4	64	25	all	..	..	2[d]	1	1	1	..	..	1	..	..	..	..	..	..	..	3
Neb. 4B17—4	63	25	all	..	..	1[d]	1	2	0	0	..	1	..	..	..	0	0	0	..	
Neb. 4B17—4	63	15	old	..	..	1	2	2	1	0	..	2	..	..	..	0	0	2	..	
Neb. 4B17—4	63	15	new	..	..	3	3	3	3	2	..	2	..	..	..	1	1	2	..	0
CURLY DWARF																				
Neb. 4A4—3	5	15	all	3	..	2	2	2	1	..	3	2	2	1	..	..	..	..	..	1
Neb. 4A4—3	6[4]	15	all	3	..	2	2	1	1	..	3	2	2	2	..	..	..	..	..	
Neb. 4A4—3	6	25	old	..	..	1	2	1	0	..	1	3	0	0	..	..	..	..	..	
Neb. 4A4—3	6	25	new	..	..	2[d]	0	1	0	..	0	3	0	0	..	..	..	..	..	1
SPINDLE-TUBER																				
Me. 36B	120	15	all	1	..	..	..	1	..	..	..	1	..	..	..	..	..	..	..	1
Me. 36A	119	15	all	..	..	..	..	0	..	..	..	0	..	..	..	..	..	..	..	
Me. 36A	119	25	old	..	..	..	..	1	..	..	..	0	..	..	..	..	..	..	..	
Me. 36A	119	25	new	..	..	..	..	1	..	..	..	2	..	..	..	..	..	..	..	3
Me. 37E	126	25	all	1	..	..	..	1	..	..	..	2	..	..	..	..	..	..	..	2
Me. 37D	125	25	all	..	..	..	..	1	..	..	..	2	..	..	..	..	..	..	..	
Me. 37D	125	15	old	..	..	..	..	1	..	..	..	2	..	..	..	..	..	..	..	
Me. 37D	125	15	new	..	..	..	..	0	..	..	..	1	..	..	..	..	..	..	..	1

[1]See Table 1. [2]d = diffuse mottling. [3]See Plate 3A. [4]See Plate 3B. [5]See Table 2, footnote 2.

slight mottling of this diffuse type that would easily be missed in a casual observation. Occasionally no mottling at all could be detected on the new leaves. Plants with mild mosaic and mild mosaic combined with spindle-tuber when grown at 25° often did not show any symptoms when they were small but when changed to a low temperature the old leaves showed slight mosaic symptoms and the new leaves were severely mottled, wrinkled, and ruffled, (Plate 4, U25-L25).

It is thus evident that the masking of mottling at high temperatures is chiefly a change in the type and degree of mottling on the old leaves, sometimes accompanied by an entire absence of mottling on the new leaves. The complete elimination of mottling at high temperatures on leaves previously showing this symptom at low temperatures has never been observed in our greenhouse experiments. It is entirely possible that mottling could be eliminated on old leaves by growing the plants at a temperature high enough to mask the mottling, changing them to a low temperature for a sufficient period to bring out the first signs of mottling and then immediately transferring them back to the high temperature. In fact, this phenomenon has often been observed in the field and has previously been recorded (3). Possibly intense sunlight during this period of high temperature assists in the change. This supplementary factor, of course, did not come into play in the greenhouse experiments. It is clearly evident that mottling becomes "fixed" with the increasing age of the foliage having this symptom.

Wrinkling and ruffling, the other two characteristic symptoms of mild mosaic, tended to disappear entirely at a high temperature; the masking of these symptoms was more complete than that occurring with mottling. The same was true of rugosity, curling, rolling, and brittleness when these symptoms occurred on mosaic plants. The change in the rolling symptoms was particularly noticeable in the "curly dwarf" plants changed from a low to a high temperature (Plate 3, B). Just what combination of diseases occurred in these plants is questionable; the symptoms differed from any of the others studied in this experiment.

In addition to the temperature effects on the above symptoms, changes were also noted in other symptoms not previously reported. In two units (medium plus mosaic) presented in Table 3 there was evidently present rugose mosaic with spindle-tuber. These plants and other rugose mosaic plants were badly affected with streaking, spotting, burning,

stem corrugations,[1] and leaf-dropping when grown at low temperatures. These symptoms, at least in the Bliss Triumph units, did not appear on plants grown at 25° C. As soon as the plants were transferred to 15°, however, these symptoms appeared and the reverse was true of plants started at 15° and changed to 25°.

While all the symptoms of mosaic tend toward masking with increase in temperature as stated above, the exact opposite condition holds true for spindle-tuber and for some of the spindle-tuber symptoms when in combination with mosaic. The general uprightness of the plants and the erect appearance of the branches and leaves, which is one of the most evident symptoms of spindle-tuber, is greatly increased by high temperature. Spindle-tuber plants grown at 15° C. were hardly discernible from the healthy controls (Plate 1), but when changed to 25° the general character of the plant growth was markedly different. The ruffling symptom of the leaves of spindle-tuber plants sometimes shows an increase with a rise in temperature but this did not occur on all plants. In general the leaves of plants affected with spindle-tuber when grown at 25° show a slight downward rolling of the leaves, and the leaves are longer, narrower, smoother and more pointed than on a healthy plant. The elongation and the paler color of the tubers when spindle-tuber plants are grown at high temperature has already been referred to and occurred again in this experiment.

The leaf roll plants used in this experiment were not changed from 15° to 25° C. until 8 weeks after emergence. The only change in the symptoms was a general chlorosis and earlier death at the higher temperature. It is possible that the rolling of the leaves would have been influenced by the high temperature if the plants had been changed at an earlier date.

EXPERIMENT IN AIR TEMPERATURE CONTROL CASES

In this experiment a more accurate control of air temperature was possible than in the experiment in the open greenhouse previously discussed. While the number of plants was smaller, the use of 4 different air temperatures accurately controlled allowed for a careful checking up of the previous experiments.

[1] "Stem corrugations" refer to peculiar necrotic areas on the stem just below the leaves. These areas are made up of parallel horizontal cracks, brown in color, extending ¼ to ½ around the stem for a distance of 1 to 2 inches below the leaf axil. These corrugations were associated with the leaf-dropping occurring with rugose mosaic.

TABLE 4—*Relation of air temperature to disease symptoms*

Source of seed	Plant No.	Air temperature °C.	Symptoms[1]															
			Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping
MILD MOSAIC																		
Neb. 4G11—1	17	14	..	..	3	2	2	..	..	..	..	..	..	..	..	..	..
Neb. 4G11—1	18	18	..	..	2	1	1	..	..	..	..	..	..	..	..	..	..
Neb. 4G11—1	19	22	..	..	1[d][2]	1	1	..	..	..	..	..	..	..	..	..	..
Neb. 4G11—1	20	26	..	..	0	0	0	..	..	..	..	..	..	..	..	..	..
SPINDLE-TUBER																		
Neb. 4B26—2	5	14	0	..	..	..	1	..	..	..	0	..	..	..	..	..	..
Neb. 4B26—2	6	18	0	..	..	..	1	..	..	..	0	..	..	..	..	..	..
Neb. 4B26—1	7	22	1	..	..	..	2	..	..	..	1	..	..	..	..	..	..
Neb. 4B26—1	8	26	1	..	..	..	2	..	..	..	3	..	..	..	..	..	..
SPINDLE-TUBER + MILD MOSAIC																		
Neb. 4B23—1	9	14	0	..	3	2	2	..	..	..	0	..	..	..	..	..	..
Neb. 4B23—1	10[3]	18	1	..	2	1	1	..	..	..	1	..	..	..	..	..	..
Neb. 4B23—2	11	22	1	..	2[d]	1	1	..	..	..	3	..	..	..	..	..	..
Neb. 4B23—2	12	26	1	..	0	0	2	..	..	..	3	..	..	..	..	..	..
MEDIUM PLUS MOSAIC (SPINDLE-TUBER + RUGOSE MOSAIC)																		
Neb. 4G17—1	13	14	0	..	2	3	3	3	3	..	0	..	..	1	1	..	1
Neb. 4G17—1	14	18	1	..	2	2	2	2	1	..	1	..	..	0	0	..	1
Neb. 4G17—1	15	22	1	..	1[d]	2	2	1	0	..	1	..	..	0	0	..	1
Neb. 4G17—1	16	26	1	..	0	1	1	1	0	..	2	..	..	0	0	..	1

[1]See Table 1. [2]*d* = diffuse mottling. [3]See Plate 4A.

Methods:—The temperatures used were 14°, 18°, 22°, and 26° C. These temperatures were obtained by electrically heated and controlled chambers placed in the refrigeration compartment of the greenhouse as described previously (5). The plants were grown in containers similar to those used in the soil temperature experiment and the soil moisture was held at the same point.

Five diseased and one control plant were grown at each temperature. When possible, all 4 plants were grown from the same mother tuber. In some instances, however, the small size of the seed made it necessary to use two tubers, in which case they were always taken from the same hill. Detailed readings were made every two weeks after emergence. At the end of the third reading some of the plants had reached the top of the cases, so that the experiment was discontinued.

During the course of the experiment, sunlight was supplemented during the short days of winter and on cloudy days by artificial light, using 1000-watt nitrogen filled lamps (Mazda C) suspended over the cases in large bowl reflectors.

Results:—A summary of the symptoms appearing on the individual plants is given in Table 4. With the mosaic plants all the symptoms were more pronounced and distinct at 14° C. than at the higher temperatures. At 26° practically all the symptoms were very indistinct or absent. With mild mosaic plants, mottling was severe at 14° C., moderate but distinct at 18°, slight and diffused at 22°, while at 26° mottling was entirely absent. Along with mottling, the symptoms of wrinkling and ruffling tended to gradually disappear as the temperature was increased.

The only two symptoms present on the spindle-tuber plants were ruffling and uprightness, both of which increased in distinctness and severity with increased temperatures. In other words, it is quite apparent that whereas the mild mosaic symptoms were masked by high temperatures, the reverse occurred in the case of spindle-tuber symptoms.

With a combination of spindle-tuber and mild mosaic, mottling and wrinkling reacted to temperature as in the case of mild mosaic. It has been shown that at low temperatures ruffling is very pronounced with mild mosaic plants whereas at high temperatures ruffling is intensified on spindle-tuber plants. Thus at 14° C. the pronounced ruffling of the mild mosaic disease appears, while at 18° and 22° it tends to disappear. However, at 26° C., where ruffling disappears in mild mosaic plants, it is intensified in spindle-tuber plants, so that ruffling is as pronounced at 26° with the combination of

spindle-tuber and mild mosaic as it is at 14°, due wholly to the two types of diseases present (Plate 4, A).

Somewhat different results were obtained with medium plus mosaic (probably spindle-tuber and rugose mosaic). Uprightness increased, mottling, wrinkling, rugosity, and curling decreased, with progressively higher temperatures, while the symptoms of spotting and streaking occurred only at 14° C. A slight leaf-dropping appeared at all temperatures. The effect of the rugose mosaic in this combination, however, resulted in a decrease in ruffling at the high temperatures in contrast to the combination of spindle-tuber and mild mosaic where the reverse occurred.

No correlation between the curly dwarf plants grown at the different temperatures can be made owing to the fact that the seed pieces planted at 22° and 26° C. failed to sprout.

The 4 control plants remained free from any symptoms thruout the experiment.

RELATION OF AIR TEMPERATURE TO DISEASE SYMPTOMS WITH THE GREEN MOUNTAIN VARIETY

All of the experiments previously recorded in this paper were conducted with the Bliss Triumph variety. Inasmuch as the published experimental and descriptive data on these diseases in the United States have in a great measure been obtained with the Green Mountain variety, it was thought that parallel experiments with plants of this variety and the Bliss Triumph variety would be well worth while in checking up the effect of temperature on these symptoms and the varietal modifications of the symptoms of these diseases.

Methods:—The tubers used in this experiment were obtained thru the courtesy of Dr. Donald Folsom, who grew one-half of each tuber in Maine to check up on the previous diagnosis while the other half was used in this experiment. Each half grown in this experiment was again divided into 2 seed pieces and planted in containers holding 10 kilograms of soil held at 1¼ M.E. Duplicate plants from the same seed tubers were grown at 25° and 15° C. Detailed readings were made as in previous experiments.

Results:—Unfortunately most of the seed used in this experiment had become infected with other degeneration diseases during the previous season. A few of the plants, however, came true to type and allowed for the following observations and comparisons.

LEAF ROLL:—Two of these plants showed the presence of mosaic, while the other two were pure leaf roll. No difference in the amount of rolling at 15° and 25° C. was observable. The rolling was more severe on the lower leaves and in no instance was it as pronounced as on the Bliss Triumph variety grown under the same conditions. Dwarfing was not as evident nor were the leaves as brittle or rigid on the Green Mountain as on the Triumphs.

LEAF-ROLLING MOSAIC:—All of these plants were affected with rugose mosaic so that no clear-cut comparisons could be made with the Bliss Triumphs. The temperature effect was the same as with all other mosaic types studied, all of the symptoms being reduced in severity at the high temperature.

MILD MOSAIC:—These units were also affected with rugose mosaic. The symptoms were not greatly masked by a temperature of 25° C., mottling being the only symptom that decreased in severity, all other symptoms remaining approximately the same at both temperatures.

RUGOSE MOSAIC:—The effect of a high temperature on the symptoms of this disease was very slight. The mottling was of the diffuse type but remained about the same at both temperatures. The other symptoms behaved likewise.

SPINDLE-TUBER:—Two of these plants were affected with rugose mosaic while the other two showed pure spindle-tuber. The ruffling of the leaves and the upright habit of the plant were much more evident at 25° than at 15° C. Both of these symptoms were much more severe than occurred in the Bliss Triumph variety (Plate 5).

Discussion:—While a relatively small number of plants (24) were grown in this experiment, certain differences were very marked and consistent. In general, it may be stated that the individual symptoms of each of the diseases were more evident and apparently more stable in the Green Mountain variety than in the Bliss Triumph. Leaf roll was the only disease in which the symptoms were more marked in the Triumphs. Likewise, masking of symptoms due to a high temperature was not as rapid nor as complete in the Green Mountains as in the Triumphs.

RELATION OF AIR TEMPERATURE AND SOIL MOISTURE TO THE SYMPTOMS OF YELLOW DWARF

In order to become acquainted with the symptoms of yellow dwarf (1), a disease which has never been reported to occur in Nebraska, and to study it in comparison with other types of degeneration diseases, a few tubers of infected Early Rose and White Rose potatoes were obtained thru the courtesy of Mr. L. M. Fenner of the Department of Plant Pathology, Cornell University.

All of these tubers showed varying amounts of cracking, internal necrosis, and stem-end rot as well as other tuber symptoms somewhat similar to those of spindle-tuber. In fact, at first glance many of the tubers had the appearance of being affected with both spindle-tuber and *Fusarium eumartii* Carp. Cultures from such tubers, however, were always sterile, and the necrotic tissues in the tuber as well as the later appearance of wilt in the plant were markedly different from those occurring with *F. eumartii* or any other disease with which the authors were familiar.

The tubers were divided into halves and grown at temperatures of 15° and 25° C. In addition, half of the plants at each temperature were grown in a very dry soil while the others were grown at a high soil moisture content.

Results:—The differences in the plants grown at different temperatures were very marked thruout the entire experiment (Plate 6). Practically no differences were noted as being due to soil moisture. Emergence naturally occurred first with the higher moisture content and at the higher temperature. After the disease symptoms appeared, the death of the plant occurred earlier with a low soil moisture, but the individual symptoms were the same at both soil moistures.

Of the 8 plants grown at 25° C., 4 of them completely wilted early in the experiment. The other 4 were very severely wilted when dug. The disease was evidenced in every case by the plants being dwarfed but with thick stems, and by early chlorosis followed by the death of the terminal shoot and later of the auxiliary buds. Discoloration of the vascular system and the pith of the stems and branches was very marked. The leaves wilted completely and there was considerable leaf-dropping both of the lower and of the upper leaves.

At 15° C. none of the plants showed symptoms of disease, aside from a slight ruffling of the leaves, thruout the entire experiment.

The symptoms on the tubers produced at the two temperatures showed as great a difference as did the foliage symptoms. Three of the plants grown at 25° C. died before any tubers were formed. The other 5 plants produced 10 small tubers, all of which showed varying degrees of cracking and internal necrosis. The 8 plants grown at 15° C. produced 26 tubers, of which 2 showed very slight internal necrosis while all the others appeared healthy.

Healthy Bliss Triumph tubers were planted in the soil in which 4 of the yellow dwarf plants had died early in the experiment. The Triumph plants produced large, healthy vines and a good crop of healthy tubers, and no evidence of the disease occurred.

While the number of plants used was rather small, the differences were more marked than with any of the other diseases studied. It was clearly evident that yellow dwarf is a high temperature disease and that it would be very hard to detect the disease at low temperatures. With high temperatures the disease is more severe in its action than any of the other degeneration diseases studied by the authors.

The symptoms of this disease are markedly different from any of those occurring with the other types of degeneration studied. Some of the symptoms of these plants, however, showed a great similarity to the spindle-tuber disease, which may have been present along with yellow dwarf. Judging from the plants used in this experiment, the authors can see no reason for believing that this disease is a combination of any of the other degeneration diseases of potatoes. The symptoms are markedly different from any type of mosaic with which the authors are familiar and the reaction of the symptoms to temperature is the exact reverse of that occurring with mosaic.

COMBINATIONS OF DEGENERATION DISEASES

In the preceding pages the symptoms of several disease units have been recorded as being a combination of two diseases on the same plant. Such combinations have been described and discussed by Schultz and Folsóm (6). Some of the seed obtained from Dr. Folsom and used in the present investigation was labelled as being a combination of two diseases (see p. 7). Such seed has produced plants having symptoms corresponding to those expected with such combinations. There has sometimes occurred, however, an evident splitting up of the combination into two distinct types of disease. This

splitting more often results in one plant showing the symptoms of a single disease while the other plant from the same unit appears as the original combination.

The authors have made no effort in the present investigation to secure accurate evidence of such combinations by inoculation methods. The evident splitting up of such combinations or the addition of new symptoms in the progeny of a plant previously showing symptoms of a single disease has been repeatedly observed, however. While these data are not directly concerned with the effect of environment on mosaic symptoms, it might be well to present typical examples in support of the data presented by Schultz and Folsom (6) and in an effort to explain some of the material presented in this paper.

Some of the units of spindle-tuber obtained in 1922 and grown in the greenhouse the following winter showed typical symptoms of spindle-tuber. No mosaic symptoms were evident. Part of these units were grown in the field in 1923. During the latter part of the summer some of the plants showed evidences of current season infection with mosaic. Some of the progeny of these plants were used in the previous experiments. One unit grown at 25° C. showed no mosaic symptoms during the first 4 to 6 weeks after planting, while very slight symptoms appeared during the later stages of growth. Table 5 presents the data obtained on 2 of these plants (Nos. 25 and 26) and these are representative of 8 plants in this unit. It is clearly evident that these spindle-tuber plants were infected with mild mosaic in the field the previous summer. It is also evident that if the tubers had been tested for mosaic in the greenhouse at a high temperature, no mosaic would have been detected until the plant was half mature (Plate 4, U25 and L25), and then the symptoms would have been hardly discernible. The same fact has often been observed in "indexing" seed in the greenhouse. It is not possible to grow a plant from a single eye to a height of 10–15 cm. and then to be certain that the tuber is not infected.

Plants from the same original units as the above, grown in other plots in the field in 1923, showed entirely different symptoms when grown in the greenhouse the following winter. Typical examples are shown in Table 5, plants Nos. 21 and 22. It is clearly evident that these spindle-tuber plants became affected with other diseases in the field. The effect of the change of temperature on the symptoms is also apparent.

While such combinations have often been recorded when plants are exposed to infection in the open field, they have

TABLE 5—*Examples of plants infected with new diseases the previous year and the splitting up of disease combinations in other plants*

Source of seed	Plant No.	Air temperature °C.	Foliage	Symptoms[1]																Remarks
				Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf-dropping	Early death	Tuber symptoms[3]	
SPINDLE-TUBER																				
Neb. 4G27—1	25	25	all	..	..	0	0	1	..	..	..	2	..	..	..	..	..	..	..		Pl.4U25-L25.Evidently was infected with mild mosaic the previous y'r.
Neb. 4G27—1	25	15	old	..	..	0	0	1	..	..	..	2	..	..	..	..	..	..	..		
Neb. 4G27—1	25	15	new	..	..	2	2	2	..	..	..	2	..	..	..	..	..	..	..	1	
Neb. 4G27—1	26	25	all	..	..	1[d][2]	..	1	..	..	..	2	..	..	..	..	..	..	..	3	No symptoms until 6 weeks after emergence.
Neb. 4F31—2	21	15	all	..	..	3	3	3	2	2	..	2	2	2	1	1	1	1	..		Evidently infected with rugose mosaic the previous year.
Neb. 4F31—2	21	25	old	..	..	2	3	3	0	0	..	2	2	0	1	1	1	1	..		
Neb. 4F31—2	21	25	new	2	..	2[d]	1	2	0	0	..	2	2	0	0	0	0	0	..	2	
Neb. 4F31- 2	22	15	all	2	..	3	3	3	1	2	..	2	..	..	1	1	1	1	..	1	
SPINDLE-TUBER + MILD MOSAIC																				
Neb. 4B21—1	35	15	all	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1	Plate 7, A.
Neb. 4B21—2	36	15	all	1	..	..	2	1	1	1	..	..	..	..	..	..	..	..	..	2	Plate 7, B.
Neb. 4B21—2	37	15	all	2	..	3	3	3	3	3	..	..	..	..	1	1	2	3	..	2	Plate 7, C.
Neb. 4B22—1	40	15	all	..	..	3	3	2	..	..	1	2	2	..	..	..	..	..	..		Plate 7, D.
Neb. 4B22—1	40	25	old	..	..	1	2	2	..	..	0	2	0	..	..	..	..	..	..		
Neb. 4B22—1	40	25	new	..	..	0	1	1	..	..	0	2	0	..	..	..	..	..	..	3	

[1]See Table 1. [2]*d* = diffuse mottling. [3]See Table 2, footnote 2.

never been found to occur on plants grown under insect cages where each single disease has always remained true to type.

The problem of diagnosing and studying these diseases is, however, often complicated by the fact that a plant affected with a combination of diseases not only may acquire another disease but may show a splitting up of these diseases in the different tubers produced or even in different eyes of the same tuber, as shown by the following example.

Plants Nos. 35, 36, 37, and 40, listed in Table 5, (Plate 7), were all originally from the same tuber in 1922, listed as spindle-tuber + mild mosaic, which when grown in the greenhouse and in the field in 1923 showed the symptoms to be expected in this combination. The plants were exposed to infection in the field in 1923, however, and the progeny when grown in the greenhouse in 1924 showed not only a splitting up of this combination but also the acquisition of new symptoms.

Plants Nos. 36 and 37 were grown from two halves of the same tuber and plant No. 35 from another tuber in the same hill; No. 40 was grown from an adjacent hill in the same unit. No symptoms of mosaic appeared on plant No. 36 grown at 15° C. Spindle-tuber could be detected in both the tops and the tubers in the mature plant. Plant No. 37 from the same mother tuber grown at the same temperature showed not only symptoms of mosaic as occurred in the preceding generation and spindle-tuber in the new tubers, but also marked rugosity, curling, spotting, streaking, burning, and leaf-dropping, as shown in Plate 7. The plant had apparently become infected with another disease, probably rugose mosaic, but this disease had not affected all the eyes in the tuber.

Plant No. 35 from another tuber from the same hill showed no symptoms of mosaic, and neither the foliage nor the tubers produced showed any serious evidences of spindle-tuber.

Plant No. 40, from an adjacent hill in the same unit, showed symptoms of mild mosaic and spindle-tuber in the same manner as evidenced in the preceding generation.

Another marked change in an entire set of tuber units occurred with the plants designated as curly dwarf. The original seed in 1922 was listed as probably being a combination of spindle-tuber + leaf-rolling mosaic. Grown in the greenhouse in 1923 the plants showed symptoms which would correspond to the above combination. In the field in 1923, however, mottling was very slight, in fact, absent during most of the season, while some streaking, burning, and leaf-dropping occurred. In 1924 the progeny of these plants grown in

the greenhouse produced the symptoms shown in Table 3, plants Nos. 5 and 6 (Plate 3, B). The most marked symptoms were the severe rolling and brittleness of the leaves at 15° C. and an entire absence of curling, streaking, burning, and leaf-dropping which had been present in the preceding generation.

DISCUSSION

The experimental results clearly show that of the environmental factors studied, light, soil moisture, and soil temperature have very little or no effect whatever upon the foliage symptoms of any of the degeneration diseases investigated. High soil moistures and high soil temperatures appeared to increase the severity of the tuber symptoms of the spindle-tuber disease. However, there is a tendency for healthy and mosaic tubers likewise to change in shape and color at high soil temperatures and appear somewhat similar to spindle-tuber potatoes.

The effect of air temperatures on the foliage symptoms of mosaic has again been found to be very pronounced and appears to be the most important factor in the masking of foliage symptoms of the degeneration diseases.

Mottling was again found to be the most constant symptom of mosaic at all temperatures, altho a change in the type and degree of mottling was clearly evident. With mild mosaic, mottling did not appear on new growth at 25° C., while the distinct mottling occurring at 15° became very indistinct or diffuse when the plants were changed to 25°. The indistinct or diffuse mottling of plants affected by rugose mosaic was not greatly changed at high temperatures.

The wrinkling, ruffling, rugosity, curling, rolling, and brittleness of mosaic plants all tended to disappear at 25° C. In addition to the masking of the above symptoms which has previously been recorded it was found that the streaking, spotting, burning, and leaf-dropping of rugose mosaic did not occur at 25° C. on Bliss Triumphs.

The symptoms of mild mosaic are so greatly masked at high temperatures that the plant often looks healthy while the other mosaic types and combinations of two mosaics or mosaic and spindle-tuber still retain enough of the symptoms at 25° C. to clearly distinguish them from mild mosaic and healthy plants. The identification of the individual disease, however, is very difficult and often impossible at 25° C.

The spindle-tuber disease reacts to temperature the exact reverse of mosaic. Plants affected with spindle-tuber were

often impossible to distinguish when grown at low temperatures, whereas the symptoms became increasingly evident as the temperature was raised. It was noticeable that ruffling, which is a leaf symptom of both mild mosaic and spindle-tuber, disappears at high temperatures with mild mosaic, while the reverse occurs with the same symptoms on spindle-tuber plants.

The symptoms of the various diseases were much more evident on plants of the Green Mountain variety than on Bliss Triumph, and the masking of symptoms at high temperatures was not nearly as great with Green Mountains.

The correlation of the results obtained in greenhouse experiments with conditions existing in the field was made in a previous publication, and the application of these results is being made in the seed potato industry in the state. The results obtained by the use of constant temperatures in the greenhouse have been found comparable to those obtained with similar mean temperatures occurring in the field. In determining the amount of mosaic in fields being grown for certification in Nebraska it has been found impossible to rely entirely upon disease readings made in the field, as the normal temperature conditions during most of the season cause considerable masking of the symptoms. Accordingly representative samples of all lots of seed are planted in western Nebraska very early and mosaic readings made on the plants in these plots when the weather conditions are favorable for the appearance of the symptoms. Even this practice does not always permit the detection of all the mosaic present, so duplicate samples of all seed planted for certification are grown in Louisiana under more favorable conditions for the appearance of the disease. If more than a specified percentage of mosaic is found to occur in either of these plots, the field being grown from the same seed is disqualified for certification[1] even tho the disease is not detected in the commercial field. It has also been found advisable to make inspections in the field at the most favorable time for the appearance of the diseases, depending on date of planting and weather conditions rather than upon set dates, and to increase the number of field inspections to at least three.

Another application of our knowledge of the masking of symptoms is also found in the usual method of indexing tubers

[1] At the present time seed potatoes in Nebraska are certified by a potato growers' organization, the certification being based upon standards set by the College of Agriculture and inspections made by men recommended by the College. The trial plots referred to above are conducted by the College, and the disease readings are made by the Seed Certification Committee of the College, on which both the Horticultural and Plant Pathology Departments are represented.

in the greenhouse. The authors have found it necessary to grow such indexed plants nearly to maturity under two different temperatures. The plants are started at about 15° C. and mosaic readings made at that temperature; when the plant is about half grown the temperature is raised to 22°–25° and spindle-tuber readings are made both on the tops and on the tubers, which can be dug before maturity in order to expedite the work. It was found that the first readings made in all these experiments when the plants were 10 to 15 cm. high were not very reliable, owing to the frequent abnormal appearance of the first leaves of healthy plants, and the apparent presence of symptoms which did not remain constant on mosaic plants and which could not be correlated with the disease known to be present. The second reading, made two weeks after the first, was found to be the most accurate reading of the disease symptoms. The high temperature indexing has been found necessary to detect the spindle-tuber disease.

While mosaic is a serious disease, especially in seed potato growing sections, it is not nearly as serious as the spindle-tuber problem in Nebraska. Spindle-tuber either alone or in combination with mosaic has always been found to reduce yields much more than any one type of mosaic. The disease also greatly retards sprouting, thus reducing the stand and resulting in a further reduction of the yield.

The combination of two or more diseases on the same plant further complicates the problem. In Nebraska it is these combinations containing spindle-tuber that are the real menace to the seed potato industry. The addition of new diseases to plants subject to infection in the field has been a matter of common occurrence. The splitting up of these combinations into separate and distinct diseases is not as common, but it has been observed even in plants grown from different portions of the same seed tuber.

It has been clearly evident in these investigations that the various types of degeneration diseases described by Schultz and Folsom do come true to type by tuber perpetuation. The similarity of some of these diseases to diseases of the same nature described by other investigators and the possible duplication of names is a question which does not properly belong in this paper. It was impossible to obtain material from European investigators[1] for a comparison of the diseases described and named by them with those of Schultz and Folsom. The identity and relation of these diseases one with the other can only be determined by cross inoculation studies

[1] Because of the federal quarantine act.

of plants growing under similar conditions. The casual description of a disease, without a statement of the environmental conditions occurring, results in considerable confusion. A statement of the symptoms occurring on some of the plants used in these experiments, without reference to the temperature at which they were grown, certainly would not allow for the identification of the disease. This is clearly illustrated in the data presented on the yellow dwarf disease, which has been held by some to be simply a synonym for a combination of two diseases previously described.

Yellow dwarf appeared as a disease distinct from any of the others studied. The effect of air temperature on the symptoms of this disease was even more marked than with mosaic, and the action was the reverse of that occurring with mosaic. At 15° C. the symptoms both on the tops and in the tubers were not evident, whereas the plants grown at 25° were severely diseased, early death resulted, and the tubers were badly diseased. The disease was not transmitted thru the soil to Bliss Triumph in the few tests made. This disease is not known to occur in Nebraska at the present time.

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[4 M]

PLATE 1

A comparison of healthy and spindle-tuber plants grown at different soil moisture contents, at 15° C. No effect of soil moisture on the symptoms was evident. (See page 10.)

Upper Row.—Healthy plants, (A) Grown at a soil moisture content of ⅔ the moisture equivalent, (B) at 1 M. E., (C) at 1¼ M. E., and (D) at 1½ M. E.

Lower Row.—Spindle-tuber plants, (A) at ⅔ M. E., (B) at 1 M. E., (C) at 1¼ M. E., (D) at 1½ M. E.

The photographs were taken at the time of the second reading. (See page 6.)

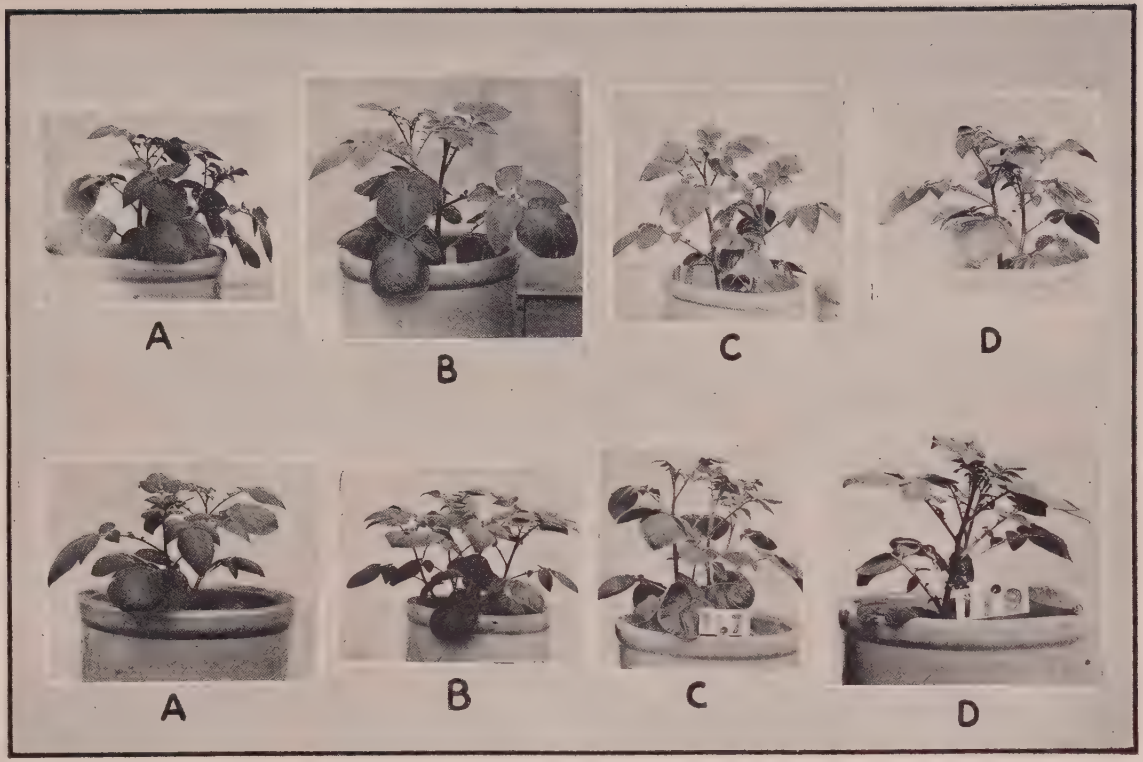


PLATE 1

PLATE 2

Plants grown at 4 different soil temperatures, but all at the same air temperature (15° C.). (A) No change of mosaic symptoms were evident. (B) High soil temperatures increased the severity of spindle-tuber symptoms but the same abnormal tuber formations occurred with healthy and mosaic plants (C). (See pages 12-15).

A.—Leaves of mild mosaic plants Nos. 25, 26, 27, and 27, grown at a soil temperature of 14°, 18°, 22°, and 26° C., respectively.

B.—Tubers from spindle-tuber plants Nos. 29, 30, 31, and 32, grown at a soil temperature of 14°, 18°, 22°, and 26° C.

C.—Tubers from mild mosaic plants Nos. 17, 18, 19, and 20, grown at a soil temperature of 14°, 18°, 22°, and 26° C.

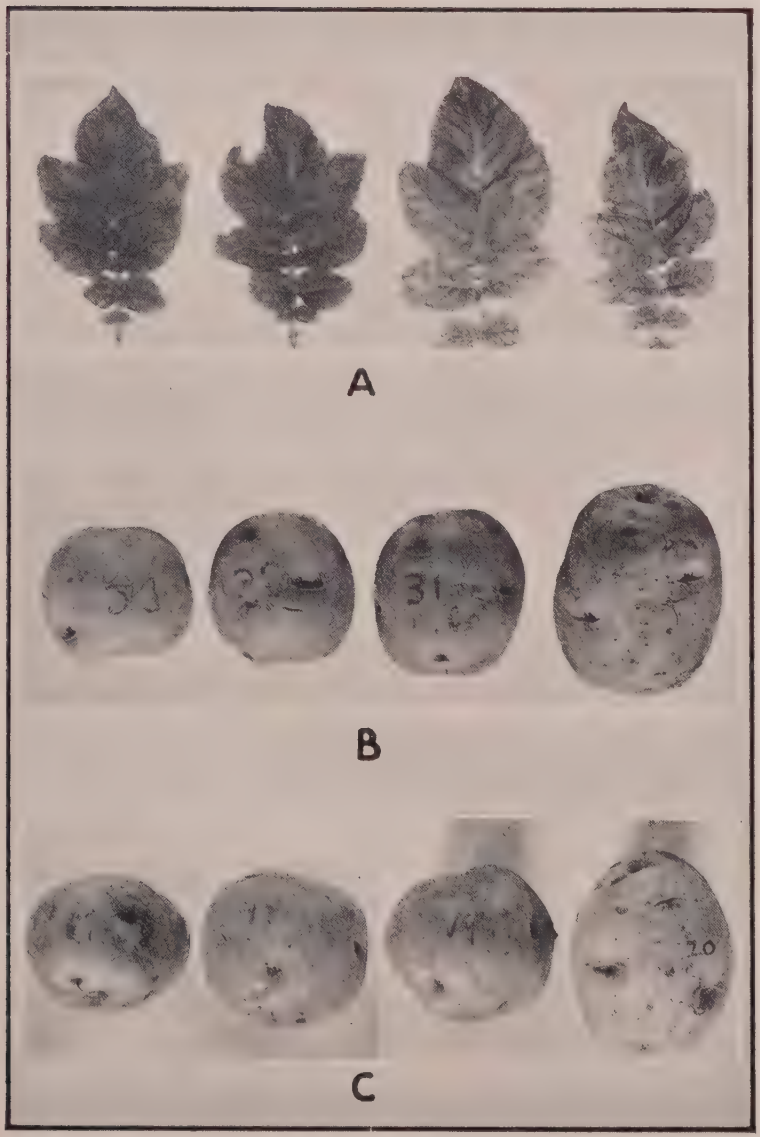

A
B
C

PLATE 3

Plants showing the masking effects of high air temperatures.

A.—Leaves of mild mosaic plant (No. 68, Table 3). (1) Leaves formed at 15° C. (2) Leaves partly out at 15° and further developed at 25° C. (3) Leaves produced at 25°, except for the tips of the leaves which show the effect of the exposure to 15° C.

B.—Curly dwarf plant (No. 6, Table 3). (1) Plant grown at 15° C. (2) Same plant 4 weeks after transfer to 25° C.


A 1
A 2
A 3
B 1
B 2

PLATE 4

A.—9 to 12.—Leaves showing the effect of high air temperature in decreasing mosaic symptoms and increasing spindle-tuber symptoms in a plant infected with both diseases. Grown in the air temperature control cases maintained at 14°, 18°, 22°, and 26° C. respectively (see page 19, and Table 4).

U-25 and L-25.—Leaves from a spindle-tuber + mild mosaic plant, which developed (U) at a temperature of 25° C. and (L) at a temperature of 15° C. (See Table 5.)


A 9
A 10
A 11
A 12
U 25
L 25

PLATE 5

Symptoms of spindle-tuber in the Green Mountain variety. (See page 23.)

A.—Spindle-tuber plant grown at 25° C.

B.—Healthy plant. Grown at 15° C.


A
B

PLATE 6

Plants and tubers of the Early Rose variety showing the effects of temperature on the symptoms of yellow dwarf. (See page 24.)

A. Plant grown at 25° C. and B, progeny.

C. Plant grown at 15° C. and D, progeny.

Both plants from same seed tuber.

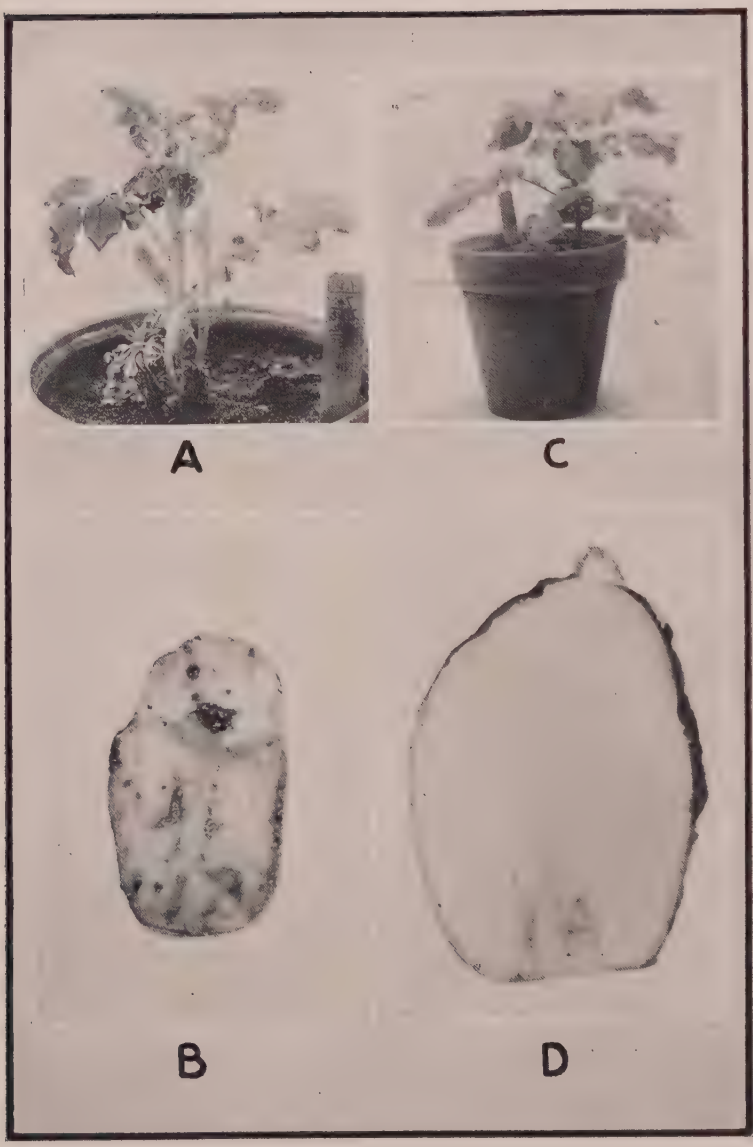

A
C
B
D

PLATE 7

Plants showing the breaking up of combinations of diseases in the same unit and tuber.

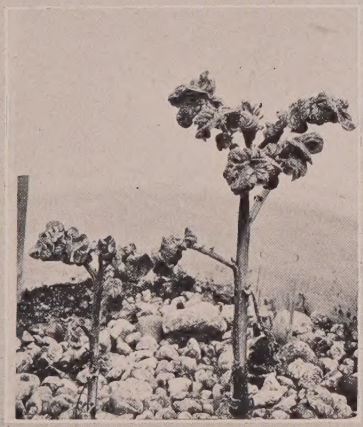
Spindle-tuber + mild mosaic plants: A, No. 35, and D, No. 40, from 2 adjacent hills of same unit, and B, No. 36, and C, No. 37, from two eyes of the same tuber, and from the same hill as A and D.

Plant D, photographed after change to 25° C., all others taken at 15° C.

(See pages 25-29, and Table 5.)

A

B



C

D